Part II
Measure Analysis and Life-Cycle Cost

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Introduction

This report presents two initiatives to upgrade and improve the 2001 California Energy Efficiency Standards for Residential and Nonresidential Buildings. The revisions will be adopted in 2003 for implementation in 2005.

Potential measure analysis initiatives and proposed standards changes were submitted and discussed at staff workshops on October 22, November 15, and November 16, 2001. The California Energy Commission (CEC) identified priority measures and funded analysis initiatives on a subset of these measures. Other parties have also funded analysis initiatives; however these analyses are not included in this document.

This document contains Part II of the CEC contractor's report, which includes the measures analyzed under contract to the CEC that will be discussed in a staff workshop on May 30, 2002. Part I was published on April 11, 2002 and the topics were discussed in the staff workshop on April 23, 2002. Additional research reports will be issued to address other topics for which research is proceeding.

Summary of Measures

The following measures and modifications are addressed in this document:

Residential Fenestration

Improve the Accuracy of Fenestration Area Allowances and Modeling Methodology. This initiative encompasses three changes to the standards and compliance calculation methodology:

- Change the prescriptive fenestration area to 20% of floor area in all climate zones.
- Limit west facing glazing area to 5% in cooling climates.
- Require that the energy budget be based on the same fenestration percentage as the proposed building.

HVAC – Hydronic System Measures

Improve the efficiency of central chilled water plants and hot water plants by requiring variable speed control of pumps and other measures. Five related hydronic measures are recommended:

- *Variable Flow Design of Chilled and Hot Water Distribution Systems.* This initiative would require for variable flow control of chilled and hot water systems through the application of two-way valves.
- *Isolation of Chillers and Boilers to Allow Pump Staging with Load.* This initiative would require either equipment isolation valves or dedicated pumps to allow for staging of pumps along with the central equipment they serve.
- *Reset of Chilled and Hot Water Temperatures for Constant Flow Systems.* This initiative would add a requirement for chilled and hot water temperature reset controls on constant flow systems (ie. three-way valves at the heating or cooling coils).
- *Isolation Valves and Variable Speed Drives for Water-Loop Heat Pumps.* This initiative would add a requirement for isolation valves on water-loop (hydronic) heat pumps as well as variable speed drives for the pumps that serve the water-loop heat pumps.
- *Variable Speed Drives and Controls for Chilled or Condenser Water Pumps Serving Variable Flow Systems.* This initiative would require variable speed drives and controls for variable flow chilled and condenser water pump systems.

Acknowledgements

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- Residential Fenestration – This study was completed by Bruce Wilcox of BSG and Ken Nittler of Enercomp, Inc.
- Hydronic System Measures – This study was developed by Jeff Stein, Mark Hydeman, and Steve Taylor of Taylor Engineering.

Residential Fenestration

Overview

This initiative proposes changes for the treatment of fenestration area under the Energy Efficiency Standards for Residential Buildings. There are three components to this proposal: changing the prescriptive fenestration area to 20% of floor area in all climate zones, limiting west-facing glass in cooling climates, and requiring that the energy budget be based on the same fenestration percentage as the proposed building.

Description

Fenestration area in the prescriptive packages is currently limited to 16% of floor area (Climate Zones 1, 2, 5, 11, 12, 13, 14, 15, and 16) or 20% of floor area (Climate Zones 3, 4, 6, 7, 8, 9, and 10). We propose simplifying the prescriptive requirement to allow a fenestration area of 20% of floor area in all climate zones.

West-facing glazing increases peak cooling loads, air conditioner sizing, and peak electrical demand. When analyzing the cost effectiveness of energy efficiency measures and calculating an energy budget for performance-based compliance, analyses assume that fenestration is split evenly between all four glazing orientations. We propose that the prescriptive requirements adopt this level of west-facing fenestration as a limit in cooling climates. Climate Zones 2, 4, 7, 8, 9, 10, 11, 12, 13, 14, and 15 would limit the west-facing glazing area to no more than 5% of the floor area. Horizontal and west-facing skylights would be defined as west-facing glazing for compliance with the 5% limit.

Currently, the energy budget used in performance compliance calculations does not change as a function of a proposed building's fenestration area. Homes with more fenestration than the prescriptive requirement must include improved energy efficiency in other building elements, while homes with less fenestration are able to pass the standard without including all cost effective energy efficiency measures. This proposed change would require that the standard design's energy budget calculation method use the same fenestration area as the proposed house's actual fenestration area or 20% of the floor area, whichever is less. Glazing area in the standard design (along with wall area) is distributed equally in the four cardinal directions.

Benefits

Adoption of this initiative will lead to energy and peak demand savings that are cost effective to home occupants and the people of the state.

Standardizing the fenestration area allowance also simplifies the compliance procedure. Limiting west-facing glazing helps keep houses that comply with the prescriptive approach building from exceeding the energy budget.

Making the window area in the standard design the same as the proposed design (up to the 20% maximum) increases the penetration rates of the prescriptive measures. Under the current performance compliance rules, only homes that are at or above the prescriptive glazing limit are required to install the full set of cost effective energy efficiency measures. Because of the relatively small fenestration area of multifamily homes, developers of these homes are able to ignore some cost effective prescriptive measures and may even install only the mandatory minimum measures. To the extent that this requirement increases the installation of cost effective prescriptive measures, total peak demand, total energy use, and total cost to comply will be reduced.

With the fenestration area allowance increasing from 16 to 20% in many climate zones, there will be fewer cases where the performance compliance approach must be used due to fenestration areas larger than the prescriptive requirements. Furthermore, the changes to the energy budget calculation method eliminates the first cost incentive to use the performance approach in low fenestration area buildings to reduce conservation measures below the prescriptive package requirements.

Environmental Impact

No known environmental impact beyond a reduction in energy usage.

Type of Change

Increasing the fenestration area allowance and limiting west-facing fenestration are changes to the prescriptive requirements. Requiring that the energy budget be based on the same fenestration percentage as the proposed building is a modeling change.

Technology Measures

The technologies involved with this update are currently in use and commonly available.

Performance Verification

The proposed fenestration changes do not require verification beyond normal compliance procedures.

Cost Effectiveness

The first proposed changes associated with this initiative, increasing the fenestration area allowance to 20% of floor area in all climate zones, allows the user additional flexibility in adhering to the standard. The second and third proposed changes, limiting the west-facing fenestration to 5% of floor area and requiring that the energy budget be based on the same fenestration area as the proposed building, improve the accuracy of the prescriptive requirements and the Alternate Calculation Method (ACM). These changes do not increase the stringency of the standard. No life-cycle cost analysis is needed.

Analysis Tools

The changes to the fenestration requirements have been analyzed using a research version of MICROPAS which includes the revised 2005 modeling assumptions and produces results in both annual and TDV terms.

Relationship to Other Measures

Changes to glazing performance have a minor impact on the cost effectiveness of other measures because they change the overall heating and cooling loads.

Methodology

The goals of this analysis are to show that: a) increasing west-facing glass increases the energy usage above the energy budget, and b) changing the fenestration area treatment will improve the energy performance of buildings.

In order to demonstrate the first goal, we calculate the energy usage twice in each climate zone and for TDV calculations as well as annual energy numbers. Energy usage is calculated once with fenestration equally distributed between all orientations, and once with 50% of the fenestration west facing and the remaining glass distributed between the non-west orientations.

The second goal, demonstrating that the new fenestration area treatment improves energy performance in buildings, requires a somewhat more involved process, due to the fact that the distribution of glazing percentages in new homes may change as a result of the new rules.

We first analyze the energy usage of homes under the current rules and the proposed rules over the range of glazing percentages found in new homes. The energy budget of new homes currently does not change with glazing percentages; therefore the CEC 1761 ft^2 prototype was calculated only once for each climate zone. In order to determine the energy usage of buildings with the proposed rules, we calculated the energy usage of the prototype building over a range of glazing areas, from 5 to 28% of floor area, for each climate zone.

We next review the current distribution of new single and multifamily houses as a function of glazing percentages. This is necessary, because most new homes are not built with exactly the prescriptive allowance glazing area. Figure 1 shows the distribution of glazing areas found in an onsite study of 752 new single and multifamily homes built statewide during 1998 and 1999[1].

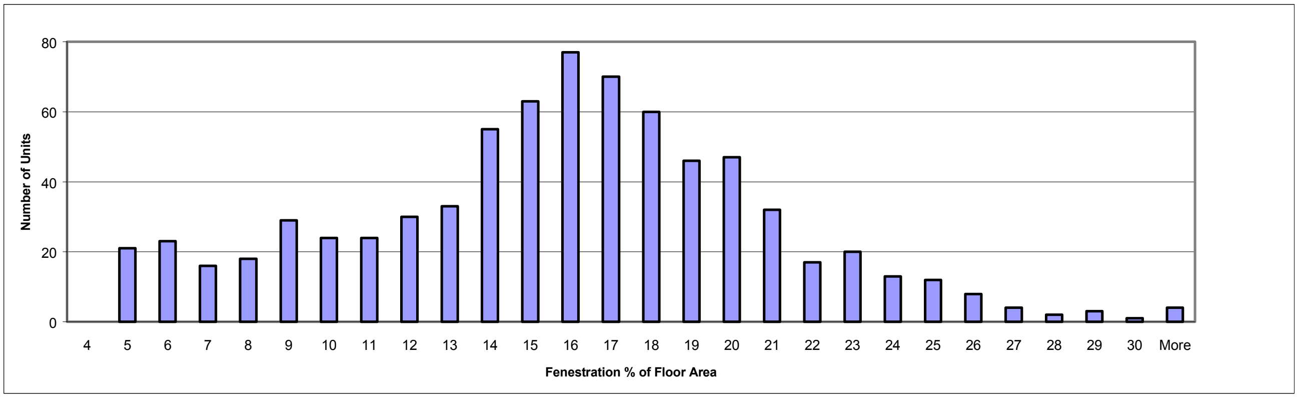

Figure 1 – Distribution of New Single and Multifamily Homes by Glazing Percentage, N=752

The study details new low-rise residential construction by utility service area and type (single versus multifamily); overall fenestration percentages are shown here. About 15% of the homes have glazing areas larger than 20% of floor area, while 45% have areas less than 16% of the floor area. These results are similar to a study carried out in 1992 for the California Energy Commission[2]. We believe the results are reasonably accurate for the current study.

Because the proposed change eliminates energy budget incentives for reducing the amount of fenestration area in a building, fenestration as a percentage of floor area may increase. In order to gauge the effect of this potential increase, we determine the energy usage of buildings using the proposed rules for the current distribution of buildings as well as the current distribution of buildings with a 1%, 2%, 3%, and 4% increase in fenestration as a percentage of floor area.

Note that there is some indirect evidence that the lack of prescriptive fenestration area limits may not appreciably affect the installed glazing area. For example, for several years the State of Oregon has had a prescriptive standard that does not limit glazing area while the State of Washington has had a code with a 15% glazing area limit similar to the current California rules. A recent study found that the fenestration areas for new single family homes were essentially identical in Washington and Oregon[3].

Finally, statewide results were calculated using a climate zone based distribution of new housing starts from the Construction Industry Research Board (CIRB). The reference case calculates the energy usage in each climate zone by multiplying the new housing starts by the standard energy budget for that climate zone. The energy usage in each climate zone is then summed together.

$$TotalEnergy = \sum_{cz=1}^{16} \left[EBCR(CZ) * Starts(CZ) \right] \text{ kBtu/ft}^2$$

1 Regional Economic Research, "Residential New Construction Study", Regional Economic Research, Inc. for Pacific Gas and Electric Company, September, 2001.

2 Wilcox, B. A., "Energy Characteristics, Code Compliance and Occupancy of California 1993 Title 24 Houses" California Energy Commission, Sacramento, CA 1995.

3 Baylon, D et al., Baseline Characteristics of the Residential Sector: Idaho, Montana, Oregon and Washington, Northwest Energy Efficiency Alliance, October 2001.

where,

EBCR = Energy budget using current rules (function of climate zone).

Starts = Number of new housing starts (function of climate zone).

cz = Climate zone.

The proposed case calculates the average energy budget for buildings using the proposed rules in a climate zone by multiplying the distribution of fenestration percentages by the energy usage as a function of fenestration percentage. This climate zone specific average energy budget is then multiplied by the new housing starts. The energy usage in each climate zone is then summed together.

$$TotalEnergy = \sum_{cz=1}^{16}\left[\left[\sum_{fa=5}^{28} UD(fa) * EBPR(CZ, fa)\right] * Starts(CZ)\right] \text{ kBtu/ft}^2$$

where,

UD = Distribution of units (function of fenestration area percentage).

EBPR(cz, fa) = Energy budget using proposed rules (function of climate zone and fenestration area percentage).

Starts = Number of new housing starts (function of climate zone).

cz = Climate zone.

fa = Fenestration area.

Results

West Facing Fenestration Area

The results below show that for the vast majority of climate zones, increasing the proportion of west-facing fenestration in a building, while keeping the total fenestration area constant, increases the energy usage of the building. This result is more dramatic when reviewing results based on TDV energy.

Table 1 shows the increase in energy use when homes with 20% of the floor area in glass have half of the glazing oriented towards the west. Most of the increased energy is for cooling and increases peak cooling loads, air conditioner sizing, and peak electrical demand. The impact is amplified under TDV.

When using the performance approach, these effects are all accounted for; the proposed house has the actual glazing orientation; and the Standard Design house has equal glazing orientation. When using the prescriptive packages, the proposed limit of 5% of floor area for west-facing glazing in cooling climate zones would ensure that the energy consumption of homes complying prescriptively, and using the prescriptive maximum for glazing, not exceed the consumption of homes complying through the performance approach. In cases where a building uses less than the prescriptive allowed window area, the 5% limit is less restrictive than the performance approach.

Table 1 – Increase in Energy Use for 50% West Compared to Equal Glass Orientation

	Annual Energy kBtu/ft^2			TDV Energy kBtu/ft^2		
CTZ	Heating	Cooling	Total	Heating	Cooling	Total
1	-0.09	0.06	-0.03	-0.06	0.13	0.07
2	0.12	0.86	0.98	0.14	1.70	1.84
3	0.15	0.51	0.66	0.16	1.08	1.24
4	0.08	0.73	0.81	0.10	1.44	1.54
5	0.04	0.25	0.29	0.06	0.31	0.37
6	0.09	0.50	0.59	0.09	1.26	1.35
7	-0.03	0.43	0.40	-0.03	1.08	1.05
8	0.01	0.85	0.86	0.01	1.89	1.90
9	0.14	0.85	0.99	0.14	1.92	2.06
10	0.14	0.99	1.13	0.15	2.17	2.32
11	0.12	1.61	1.73	0.13	3.26	3.39
12	0.16	1.48	1.64	0.17	3.03	3.20
13	0.07	1.92	1.99	0.09	3.82	3.91
14	0.20	1.84	2.04	0.21	4.11	4.32
15	0.12	1.62	1.74	0.11	3.57	3.68
16	0.34	1.52	1.86	0.37	3.06	3.43

Fenestration Area

Under the current performance analysis rules for fenestration area, every house of the same floor area in a climate zone is allowed to use the same amount of total energy. This level of energy use (shown in Figure 2 by the horizontal line at 42 kBtu/ft^2-yr) is established by simulating a Standard Design house with the prescriptive glazing area equally oriented and all the other prescriptive measures installed. Homes with glass areas larger than the prescriptive fenestration area limit have to install conservation measures that go beyond the prescriptive standards (such as higher efficiency air conditioning or increased insulation) to bring their annual energy use down to less than the Standard Design budget. Houses which have smaller fenestration areas are encouraged to remove some or all of the prescriptive conservation measures until their annual energy use is just less than the Standard Design budget. Under the proposed fenestration area rules, the Standard Design budget for homes with less than the prescriptive limit of 20% would go down as glazing area is reduced (shown by the sloping line). The old and new approach budgets are the same at the old prescriptive glazing area (16% of floor area in Figure 2). For homes with less glass area, the proposed new budget is reduced, saving energy and peak. For homes with more than the old prescriptive fenestration area in zones where it was 16%, the budget is increased. In zones where the old prescriptive glazing area was 20%, the budget is decreased for homes with glazing areas smaller than 20% and the same as it was for homes with more than 20%.

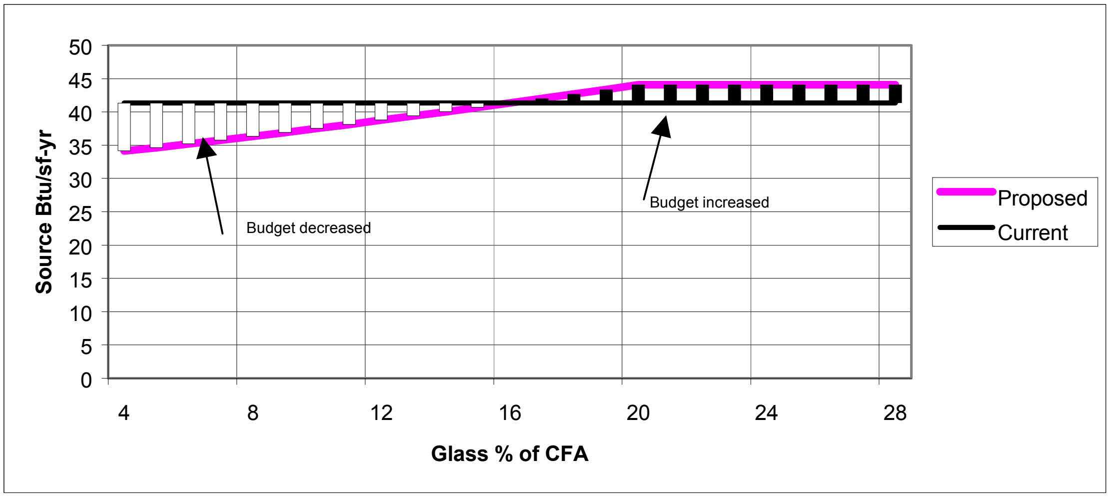

Figure 2 – Comparison of Current and Proposed Energy Budget, Climate Zone 13, Annual Calculation

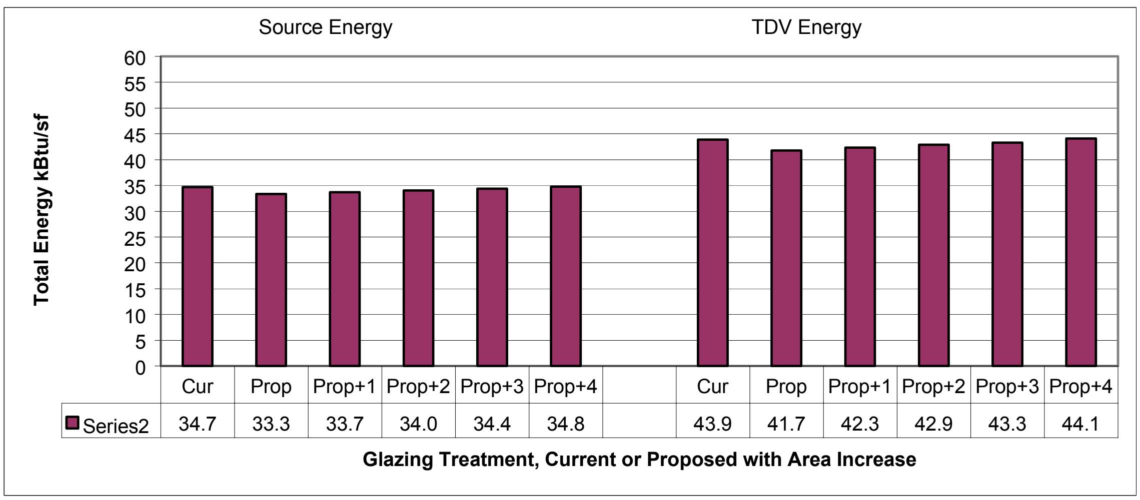

Figure 3 – Statewide Average kBtu/ft2 vs. Fenestration Area Treatment

The statewide impact of the fenestration area rules change is shown in Figure 3 in both Source and TDV energy terms. This calculation includes the effect of glazing percentage distribution and new construction activity in each climate zone as discussed in the Methodology section above. The first bar in each group is the average energy use per ft^2 of floor area for the current fenestration area rules. The second bar in each group shows the same for the new proposed rules, assuming that builders do not increase the glazing area as a result of the rule change. The proposed rule saves about 5% of the total statewide energy use calculated in either Source or TDV terms.

It is possible that the increase in prescriptive fenestration area in some zones and the removal of compliance credit for small fenestration areas will lead builders to increase the fenestration area of new homes, reducing the statewide savings from the new rules. The remaining bars show the impact of a general increase in fenestration areas. The bar labeled Prop+1 is the statewide impact if each home increases its fenestration area 1% of the floor area (from 12 to 13%, from 19 to 20%, etc.). Prop+2 through Prop+4 are corresponding impacts with larger increases. Even if each home were to increase glazing area 3% of the floor area (about a 20% increase in glass area), there would still be a statewide energy savings.

Recommendations

We recommend increasing the fenestration area allowance and limiting west-facing fenestration. These are changes to the prescriptive requirements and will require changes to the standards, the Residential Manual, the ACM Manual, and compliance forms.

We further recommend requiring that the energy budget be based on the same fenestration percentage as the proposed building. This is a modeling change that will require changes to the Residential Manual, the ACM Manual, and the compliance forms.

The proposed language changes are divided into two sections—revisions that change the standards and revisions that clarify existing language. The clarifying changes are not intended to change the requirements of the standards, but are efforts to simplify and standardize the language used to reference fenestration product ratings.

Proposed Standards Language

Revisions that change standards requirements in Section 151(f). To save space, changes to Tables 1-Z1 through 1-Z16 are shown in text form. A sample Table 1-Z12 is provided at the end of this section to illustrate the proposed changes.

1. Revise Tables 1-Z1 through 1-Z16 to read “<u>FENESTRATION</u>~~GLAZING~~”.
2. Revise Tables 1-Z1, 1-Z3, 1-Z5, 1-Z6, and 1-Z16 to add a line for “<u>Maximum solar heat gain coefficient (SHGC)</u>”. For Packages C and D, set the value to “<u>NR</u>”.
3. Revise Tables 1-Z2, 1-Z4, and 1-Z7 through 1-Z15 to add a line for “<u>Maximum solar heat gain coefficient SHGC)</u>”. For Packages C, set the value to “<u>0.40</u>”; for package D, set the value to “<u>0.40</u>”.
4. Revise Tables 1-Z1, 1-Z2, 1-Z5, and 1-Z11 through 1-Z16 so that the “Maximum total area” for Package D is “<u>20%</u> ~~16%”~~.
5. Revise Tables 1-Z1, 1-Z3, 1-Z5, 1-Z6, and 1-Z16 to add a line for “<u>Maximum west-facing area</u>”. For Packages C and D, set the value to “<u>NR</u>”.
6. Revise Tables 1-Z2, 1-Z4, and 1-Z7 through 1-Z15 to add a line for “<u>Maximum west-facing area</u>”. For Packages C and D, set the value to “<u>5%</u>”.
7. Revise Tables 1-Z1 through 1-Z16 to delete entire section on “~~SOLAR HEAT GAIN COEFFICIENT~~”.
8. Add to Section 151(f)3 a new Section C to read “<u>C. For Package D, the west-facing fenestration area shall not exceed the percentage of conditioned floor area specified in Tables 1-Z1 through 1-Z16. West-facing fenestration area includes skylights tilted to the west or tilted in any other direction at a pitch of less than 1:12.</u>”

Revisions that improve existing language. The main changes are to simplify all references to fenestration product performance by consistently referencing Section 116, and to allow prescriptive compliance through an area-weighted average U-factor and SHGC:

9. Delete Section 151(e)5 “~~5. The U-factor of installed manufactured fenestration products shall be those certified by an approved independent certification organization in accordance with Section 116. The U-factor of field-fabricated fenestration products shall be those values from Section 116, Table 1-D based on an approved method that determines the area weighted average U-factor for generic types of products.~~”
10. Revise title of Section 151(f)3A to read “3. <u>Fenestration</u>. ~~Glazing.~~”
11. Revise Section 151(f)3A to read “A. Installed fenestration products shall have <u>an area weighted average</u> U-factor~~s~~ equal to or lower than those shown in Tables 1-Z1 through 1-Z16. The U-factor<u>s</u> of installed fenestration products shall be <u>determined in accordance with Section 116</u> ~~pursuant to Section 151 (e) 5~~.”
12. Revise Section 151(f)3B to read “B. Total <u>fenestration</u> ~~glazing~~ area shall not exceed the percentage of conditioned floor area specified in Tables 1-Z1 through 1-Z16.

13. Revise Section 151(f)4 to read "4. Shading. Where Tables 1-Z1 through 1-Z16 require a solar heat gain coefficient (SHGC), ~~of 0.40 or lower~~ the requirements shall be met by either:"
14. Revise Section 151(f)4A to read "~~A. A fenestration product listed by the manufacturer to have the required solar heat gain coefficient; or~~ Installing fenestration products, except for skylights, that have an area weighted average SHGC equal to or lower than those shown in Tables 1-Z1 through 1-Z16. Skylights shall have an SHGC equal to or lower than those shown in Tables 1-Z1 through 1-Z16. The solar heat gain coefficient of installed fenestration products shall be determined in accordance with Section 116; or"
15. Revise Footnote 3 to Tables 1-Z1 through 1-Z16 in Section 151(f) to read "~~For glazing U-factor rating procedures and labeling requirements see Section 116 (a) 2.~~ The installed fenestration products shall meet the requirements of Section 151(f)3 and 151(f)4."
16. Revise Tables 1-Z1 through 1-Z16 so that all of the equipment efficiencies specified in Package C are set to "MIN" to match treatment in Package D.
17. Delete Footnote 4 to Tables 1-Z1 through 1-Z16 in Section 151(f) and renumber following footnotes.

SAMPLE TABLE 1-Z12—ALTERNATIVE COMPONENT PACKAGES FOR CLIMATE ZONE 12

COMPONENT	PACKAGE C[1]	D
BUILDING ENVELOPE		
Insulation minimums[2]		
Ceiling	R49	R38
Wood-frame walls	R29	R19
"Heavy mass" walls	NA	(R4.76)
"Light mass" walls	NA	NA
Below-grade walls	NA	R0
Slab floor perimeter	R7	NR
Raised floors	R30	R19[2]
Concrete raised floors	NA	R4
Radiant Barrier	REQ	REQ
FENESTRATION[3] ~~GLAZING~~		
Maximum U-factor[3]	0.40	0. 65
Maximum Solar Heat Gain Coefficient (SHGC)	0.40	0.40
Maximum total area	16%	20~~16~~%
Maximum west facing area	NR	5%
~~SOLAR HEAT GAIN COEFFICIENT~~[4]		
~~South-facing glazing~~	~~0.40~~	~~0.40~~
~~West-facing glazing~~	~~0.40~~	~~0.40~~
~~East-facing glazing~~	~~0.40~~	~~0.40~~
~~North-facing glazing~~	~~0.40~~	~~0.40~~
THERMAL MASS[5]	REQ	NR
SPACE-HEATING SYSTEM[6]		
Electric-resistant allowed	Yes[7]	No
If gas, AFUE =	MIN~~78%~~	MIN
If heat pump, split system HSPF[8] =	MIN~~6.8~~	MIN
Single package system HSPF =	MIN~~6.6~~	MIN
SPACE-COOLING SYSTEM		
If split system A/C, SEER =	MIN~~10.0~~	MIN
Thermostatic expansion valve	REQ	REQ*
If single package A/C, SEER =	IN~~9.7~~	MIN
SPACE CONDITIONING DUCTS		
Duct sealing	REQ	REQ*
DOMESTIC WATER-HEATING TYPE		
System must meet budget, see Section 151 (b) 1 and (f) 9	Any[9]	Any

*Alternative to Package D not yet established ~~As an alternative under Package D, glazing with a maximum 0.40 U-factor and maximum 0.35 Solar Heat Gain Coefficient, and an 11.0 SEER space-cooling system can be substituted for duct sealing and a thermostatic expansion valve. All other requirements of Package D must be met.~~

Proposed ACM Language

1. Revise Section 3.2.11 "***Standard Design:*** If the *Proposed Design* fenestration area is less than the package D specification, the *Standard Design* fenestration area is set equal to the *Proposed Design* fenestration area. Otherwise, the *Standard Design* fenestration area is equal to the package D specification. The *Standard Design* fenestration area is distributed equally between the four main compass points—north, east, south, and west. ~~Fenestration area in the *Standard Design* is determined by the package D specification for the appropriate climate zone. If package D for the climate zone permits 20% of the conditioned floor area in glass, then the *Standard Design* has a fenestration area equal to 5% of the conditioned floor area facing in the direction of each major compass point. If package D for the climate zone permits 16% of the conditioned floor area in glass, then the Standard Design has a fenestration area equal to 4% of the conditioned floor area facing in the direction of each major compass point.~~ There is no skylight area in the *Standard Design* run. The net wall area on each orientation is reduced by the fenestration area (and door area) on each facade."

Hydronic System Measures

Overview

This initiative reviews a number of hydronic system measures that were adopted by ASHRAE/IES Standard 90.1-2001. The ASHRAE cost benefit analysis values future energy savings less than with Title 24, and each component measure is found to be cost effective for California. This initiative evaluates five related measures that were evaluated individually:

1. Variable flow design of chilled and hot water distribution systems.
2. Isolation of chillers or boilers to allow pump staging with load.
3. Reset of chilled and hot water temperatures for constant flow systems.
4. Isolation valves for water-loop heat pumps for variable speed drives or the pumps that serve them.
5. Variable speed drives and controls for chilled and condenser water pumps serving variable flow systems.

All of these measures are derived from ASHRAE/IES Standard 90.1-2001. Following the Overview section of this report, we diverge from the normal chapter organization and separately describe each of the proposed hydronic measures. For each component measure, a more detailed description is provided along with a summary of the Standard 90.1 requirement and an analysis that shows that the measure is cost effective for California.

Description

The current ASHRAE/IES Standard 90.1-2001 requirements are as follow:

> *6.3.4 Hydronic System Design and Control. HVAC hydronic systems having a total pump system power exceeding 10 hp shall meet provisions of 6.3.4.1 through 6.3.4.4.*
>
> *6.3.4.1 Hydronic Variable Flow Systems. HVAC pumping systems that include control valves designed to modulate or step open and close as a function of load shall be designed for variable fluid flow and shall be capable of reducing pump flow rates to 50% or less of the design flow rate. Individual pumps serving variable flow systems having a pump head exceeding 100 ft and motor exceeding 50 hp shall have controls and/or devices (such as variable speed control) that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow. The controls or devices shall be controlled as a function of desired flow or to maintain a minimum required differential pressure. Differential pressure shall be measured at or near the most remote heat exchanger or the heat exchanger requiring the greatest differential pressure.*
>
> *Exceptions to 6.3.4.1:*
>
> *(a) Systems where the minimum flow is less than the minimum flow required by the equipment manufacturer for the proper operation of equipment served by the system, such as chillers, and where total pump system power is 75 hp or less.*
>
> *(b) Systems that include no more than three control valves.*
>
> *6.3.4.2 Pump Isolation. When a chilled water plant includes more than one chiller, provisions shall be made so that the flow in the chiller plant can be automatically reduced, correspondingly, when a chiller is shut down. Chillers referred to in this section, piped in series for the purpose of increased temperature differential, shall be considered as one chiller.*
>
> *When a boiler plant includes more than one boiler, provisions shall be made so that the flow in the boiler plant can be automatically reduced, correspondingly, when a boiler is shut down.*

6.3.4.3 Chilled and Hot Water Temperature Reset Controls. Chilled and hot water systems with a design capacity exceeding 300,000 Btu/h supplying chilled or heated water (or both) to comfort conditioning systems shall include controls that automatically reset supply water temperatures by representative building loads (including return water tem-perature) or by outside air temperature.

Exceptions to 6.3.4.3:

(a) Where the supply temperature reset controls cannot be implemented without causing improper operation of heating, cooling, humidifying, or dehumidifying systems.

(b) Hydronic systems, such as those required by 6.3.4.1, that use variable flow to reduce pumping energy.

6.3.4.4 Hydronic (Water Loop) Heat Pump Systems. Each hydronic heat pump shall have a two-position automatic valve interlocked to shut off water flow when the compressor is off.

Benefits

These measures will result in significant energy savings.

Environmental Impact

These measures have no adverse environmental impact, although there are considerable positive benefits related to energy savings.

Type of Change

These would be new prescriptive requirements. Changes will be made to the standards as well as the supporting ACM Manual and Nonresidential Manual. As prescriptive requirements, tradeoffs could be made through the whole building compliance method.

Measure Availability and Cost

These measures deal with equipment and controls that are readily available in the marketplace. More detailed cost data is involved with each of the component measures below.

Useful Life, Persistence and Maintenance

These measures are expected to have reliable performance throughout their expected lives. Aside from periodic recalibration of control sensors, these measures require little or no maintenance. Variable speed drives and control components should last at least 15 years, the study period assumed for HVAC systems and equipment.

Performance Verification

The calibration and operation of all HVAC systems and equipment needs to be verified as part of the start-up and commissioning phase. The proposed measures add some additional equipment and controls, but no special performance verification requirements are recommended.

Cost Effectiveness

A simple life-cycle cost analysis is included in the analysis of each component measure below.

Analysis Tools

DOE-2.2 is used to evaluate the measures, because of its advanced features for modeling the proposed hydronic measures.

Relationship to Other Measures

Not applicable.

Bibliography and Other Research

American Society of Heating, Refrigerating and Air Conditioning Engineers, ANSI/ASHRAE/IESNA Standard 90.1-2001, Atlanta GA.

Hydronic Measure #1 – Variable Flow

This measure would require variable flow in chilled and hot water systems through the application of two-way valves. Chilled and hot water systems are often designed with three-way valves for a number of reasons, including simplicity and historical precedent. Two-way coil valves are less expensive than three-way valves, but are often not used because the resulting designs and control strategies may need to be more complex due to changing flow and pressures caused by changing valve positions. However, even with constant speed pumps, variable flow (enabled by the two-way valves) will use less energy than constant flow.

If minimum flow is required to protect the central heating (boilers) or cooling (chillers) equipment,[4] a replacement of all three-way valves with two-way valves is not an acceptable design. Where required, minimum flow can be ensured either through distribution system design (e.g., through design of a primary/secondary distribution system), by a controlled bypass valve, or by retaining some three-way valves in the system. For the purpose of this study we evaluated the latter system (retention of some three-way valves) as it costs less than a system with all three-way valves.

Existing ASHRAE/IES Standard 90.1-2001 Requirement

The current ASHRAE/IES Standard 90.1-2001 requirement is as follows:

> *6.3.4 Hydronic System Design and Control. HVAC hydronic systems having a total pump system power exceeding 10 hp shall meet provisions of 6.3.4.1 through 6.3.4.4.*
>
> *6.3.4.1 Hydronic Variable Flow Systems. HVAC pumping systems that include control valves designed to modulate or step open and close as a function of load shall be designed for variable fluid flow and shall be capable of reducing pump flow rates to 50% or less of the design flow rate.*
>
> *Exceptions to 6.3.4.1:*
>
> *(a) Systems where the minimum flow is less than the minimum flow required by the equipment manufacturer for the proper operation of equipment served by the system, such as chillers, and where total pump system power is 75 hp or less.*
>
> *(b) Systems that include no more than three control valves.*

The rationale for exempting small systems (those 10 hp and smaller and with only three control valves) is that these systems have low pumping power so the potential savings of variable flow is small. Exception (a) is directed to small and medium sized plants with equipment that have minimum flow requirements, such as all chiller plants and some boiler plants. The exception allows greater than 50% minimum flow if required by the equipment minimum flow requirement. The limitation of this exception to 75 hp assumes that other more

[4] Some boilers do not require variable flow.

efficient means to provide minimum flow, such as primary-secondary pumping configurations and a bypass leg with a control valve, will be cost effective for larger plants.

Cost Data

Two-way valves generally cost less than three-way valves. The valves themselves cost less and the piping installation cost is lower because the valve bypass piping and balance valve are eliminated. Two-way valve actuators must have higher shut off pressure capabilities than three-way valves for pumping systems that do not have pressure controls (such as variable speed drives), but the cost-add is usually small relative to the installation savings. Also, the relatively high, reduced pump flow rate requirement of 50% of the design flow rate minimizes the need for higher shut off pressure; a lower reduced pump flow rate, such as 25%, would further increase the pump's need to "ride up its curve" and increase differential pressure across the valve[5].

For systems with minimum flow limitations, primary-secondary pumping or a controlled bypass is usually provided at some cost. However, it is not necessary to determine or justify this cost because these additional features, while desirable in most plants, are not required to comply with the proposed requirement:

- For single chiller/boiler plants, the minimum flow requirement can be met by installing sufficient three-way valves in the system. No added pumps or bypass are required. The resulting system cost is still less than an all-three-way valve system due to the lower cost of the two-way valves.
- For multiple chiller/boiler plants, the required 50% flow reduction can be obtained by staging pumps with chillers/boilers; no change needs be made to a three-way valve distribution system. Again, there are no additional first costs for this design.

Life-Cycle Cost Analysis

Chilled and hot water variable flow systems always save energy compared to constant flow systems even without pump controls, since centrifugal pump power always reduces as the flow decreases and the pump "rides up the pump curve." Savings increase if a variable speed drive (VSD) is also used (see Figure 13 below).

Because first costs required to comply with the proposed requirement are not higher than a constant flow system, and because energy costs will always be lower, the requirements are cost effective.

Proposed Title 24 2005 Prescriptive Requirement

144(x) Hydronic Variable Flow Systems. HVAC chilled and hot water pumping shall be designed for variable fluid flow and shall be capable of reducing pump flow rates to no more than the larger of: a) 50% or less of the design flow rate; or b) the minimum flow required by the equipment manufacturer for the proper operation of equipment served by the system, such as chillers.

Exceptions to 144(x): Systems that include no more than three control valves.

Modifications from the 90.1 language include:

- The language regarding valves opening and closing with changes in load was changed simply to refer to hot and chilled water systems directly, to be clearer. There are efficient system designs that do not use any control valves, such as single coil applications where coil capacity is adjusted by resetting chilled water temperature, but these are exempted by the exception. Condenser water systems generally do not have control valves so they also are exempted by the exception.
- The 10 hp limit was deleted in part because variable flow adds no costs, so is cost effective at any size. Also the life-cycle cost analysis for variable speed drives shows that they are cost effective down to 5 hp; a

---

5 Constant speed pumps that serve variable flow systems will produce higher head as the flow drops off due to the characteristics of the pumps impellor. Since pump characteristics are described by manufacturers in graphs of head versus flow depicting the impeller curves this of increased head at lower flow is called "riding the curve."

10 hp limit would have preempted this requirement. Finally, deleting this limit obviates the need to define "pump system horsepower."

- Exception (a) in the 90.1 language was poorly worded because it exempts systems serving equipment with minimum flow limits from the requirement for variable flow when it should only allow an increase in the 50% minimum flow criterion. The revised language makes this distinction clearer.

Hydronic Measure #2 – Isolation of Chillers and Boilers

This measure would require either equipment isolation valves or dedicated pumps to allow for staging of pumps along with the central equipment they serve.

Heating and cooling plants are often designed with chillers/boilers and multiple pumps piped in parallel through a single header and without isolation valves. Without the ability to shut off flow through individual chillers (or boilers), both chillers (or boilers) must be run in order to supply water at the desired temperature, while the low load operation of the chillers (or boilers) reduces the efficiency of the equipment. Furthermore, the design requires both pumps to operate even if the chillers (or boilers) have a minimum flow requirement below what could be provided by running one pump alone. Note that the design in Figure 4 has no way to automatically shut off flow through the chillers (or boilers).

This measure would require either equipment isolation valves or dedicated pumps to allow for staging of pumps along with the central equipment they serve in heating and cooling plants. This allows only one chiller (or boiler) to operate at low loads and, where a minimum flow rate is required through chillers (or boilers), it allows pumps to be staged with the load.

This measure targets projects with multiple pumps piped in parallel through a single header where no isolation valve is provided (see Figure 4). This measure requires either automatic isolation valves at each chiller (or boiler) where the pumps are headered (see Figure 5) or piping pumps in a dedicated manner to each chiller (or boiler) (see Figure 6).

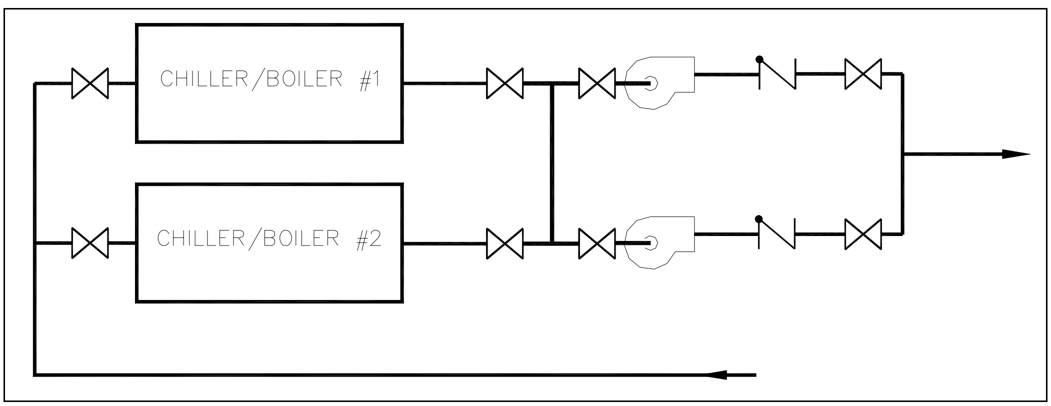

Figure 4 – Base Case - No Isolation

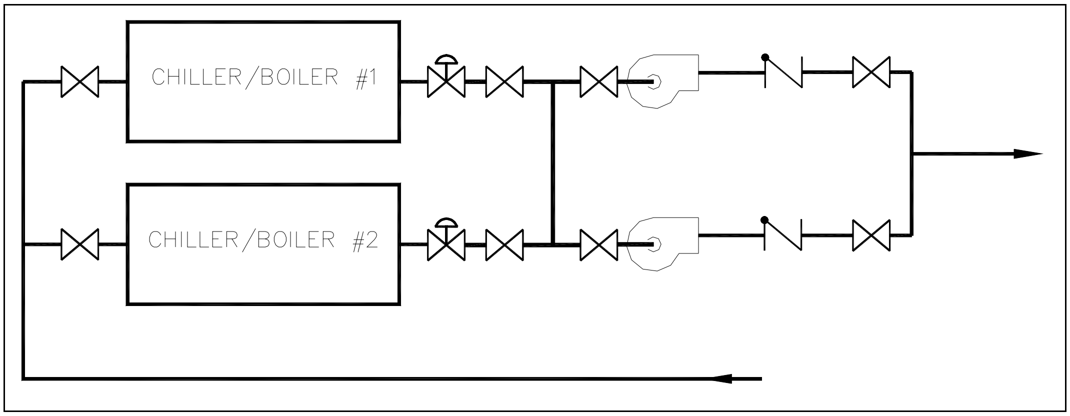

Figure 5 – Proposed Case - With Isolation

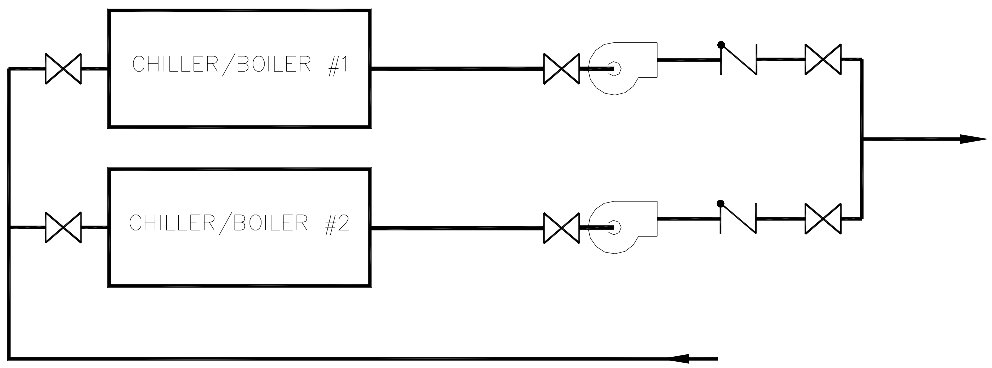

Figure 6 – Alternate Design – Dedicated Pumps

Existing ASHRAE/IES Standard 90.1-2001 Requirement

The current ASHRAE/IES Standard 90.1-2001 requirement is as follows:

> *6.3.4 Hydronic System Design and Control. HVAC hydronic systems having a total pump system power exceeding 10 hp shall meet provisions of 6.3.4.1 through 6.3.4.4.*
>
> *…*
>
> *6.3.4.2 Pump Isolation. When a chilled water plant includes more than one chiller, provisions shall be made so that the flow in the chiller plant can be automatically reduced, correspondingly, when a chiller is shut down. Chillers referred to in this section that are piped in series for the purpose of increased temperature differential, shall be considered as one chiller.*
>
> *When a boiler plant includes more than one boiler, provisions shall be made so that the flow in the boiler plant can be automatically reduced, correspondingly, when a boiler is shut down."*

Modeling

We evaluated this measure using the eQUEST (DOE 2.2) program as described below. We compared a plant with two chillers that run in parallel with their associated pumps throughout the entire range of loads to a plant that stages chillers and pumps in response to the loads. The cost premium for staging pumps is the cost of isolation valves at the chillers. We also performed a similar analysis with boilers.

Base Case Model

The assumptions for the base case model are as follows. The building and system models just meet the existing Title 24-2001 requirements. The same building and system models have been used in the evaluation of other HVAC measures:

- A 200,000 ft^2 office building.
- VAV with hot water reheat.
- One air handler with two-way chilled water valve.
- Water-cooled chilled water plant.
- Primary/secondary chilled water distribution system.
- Plant was sized at 125% of peak load.
- Two equally sized centrifugal chillers, with T-24 default efficiency and curve coefficients.
- Chiller min operating point = 1% (DOE-2 does not do a good job modeling start/stop losses).
- Chiller hot gas bypass point = 15 (per ACM for min operating point).
- Two equally sized primary chilled water pumps headered together with check valves at pump discharge.
- Primary chilled water pump head = 30 ft.
- No isolation valves at chillers. When plant is operating both chillers must operate in parallel.
- Plant control strategy: both primary pumps and both chillers operate anytime there is a chilled water load.
- 44°F chilled water supply temperature with a design delta-T of 15°F.
- Two equally sized atmospheric boilers, with T-24 default efficiency and curve coefficients. The savings would be even larger for induced- or forced-draft boilers since they have better part load performance.
- Primary/secondary hot water pumping scheme.
- Primary hot water pump head = 5 ft.

Proposal Model

The proposed case chiller isolation model uses the same assumptions as the base case model except as noted below:

- Automatic chilled water isolation valves at each chiller.
- Plant control strategy: run one primary chilled water pump and one chiller until load exceeds the capacity of one chiller. Then run both pumps and chillers equally.

The proposed case boiler isolation model uses the same assumptions as the base case model except as noted below:

- Automatic isolation valves at each boiler.
- Plant control strategy: run one primary hot water pump and one boiler until load exceeds the capacity of one boiler. Then run both pumps and boilers equally.

Cost Data

We used our office standard practice to size chilled and hot water pipes for several plant sizes. For pipe sizing we assumed:

- Chilled water delta T of 15°F.

- Hot water delta T of 30°F.
- Non-noise sensitive.
- Constant flow.

The additional components required for this proposal that result in increased incremental costs are:

- Line size butterfly valve with actuator (one per chiller/boiler).
- Controls and labor to wire and program two new isolation valve points. This is roughly $500 per point.

Table 2 shows the total installed cost for electric two-position butterfly valves of varying sizes. The cost includes a multiplier to convert national average costs to California averages.

Table 2 - Means Cost Data for Automatic Isolation Valves

code	size	total cost	CA mult.	total
13838 - 7210	1/2"	$ 218	113	$ 246
7220	3/4"	$ 325	113	$ 367
7230	1"	$ 390	113	$ 441
7240	1.5"	$ 425	113	$ 480
7250	2"	$ 620	113	$ 701
7560	2.5"	$ 550	113	$ 622
7570	3"	$ 730	113	$ 825
7580	4"	$ 1,050	113	$ 1,187

Life-Cycle Cost Analysis

Chiller Isolation Results

Figure 7 shows the simulation model results for Climate Zones 12 (Sacramento Area) and 3 (Bay Area). These two zones were chosen because they are the two largest zones in the state (in terms of projected new construction), and they represent two climate extremes, thereby bracketing operation throughout the range of California climates. As expected, the total energy use and the savings are higher in Sacramento, but the savings per installed ton are slightly higher in the Bay Area because the plant is smaller.

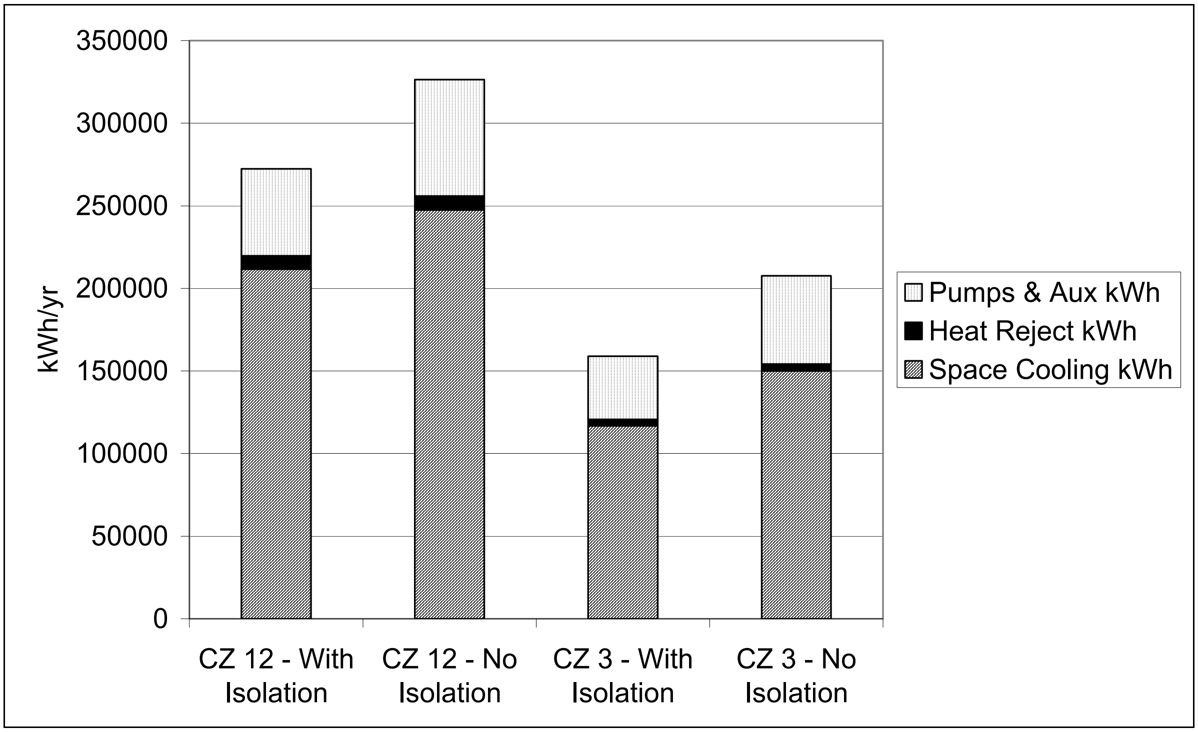

Figure 7 – Plant Energy With and Without Chiller Isolation Valves

Simulation results for chiller isolation in Climate Zones 3 and 12.

Table 3 – Simulation Results for Chilled Water Pump Isolation in Climate Zones 3 and 12

Climate Zone	kWh savings per installed ton	Peak Load from Model (tons)
3	106	367
12	103	420

We conservatively estimated a statewide average savings of 100 kWh/yr-ton. We used this same number for all plant sizes. Table 4 shows the life-cycle cost for chiller isolation valves for several plant sizes. Cost savings are based on a present worth factor of $1.37/kWh of electricity. Clearly, chiller isolation is highly cost effective for all plants with multiple chillers. This is also illustrated in Figure 8.

Table 4 – Chiller Isolation Costs and Savings

Plant size (tons)	Tons/Chiller	DeltaT	GPM/chiller	Pipe Size	Cost	Savings	NPV
100	50	15	80	3"	$ 2,650	$ 13,700	$ 11,050
200	100	15	160	4"	$ 3,373	$ 27,400	$ 24,027
300	150	15	240	4"	$ 3,373	$ 41,100	$ 37,727

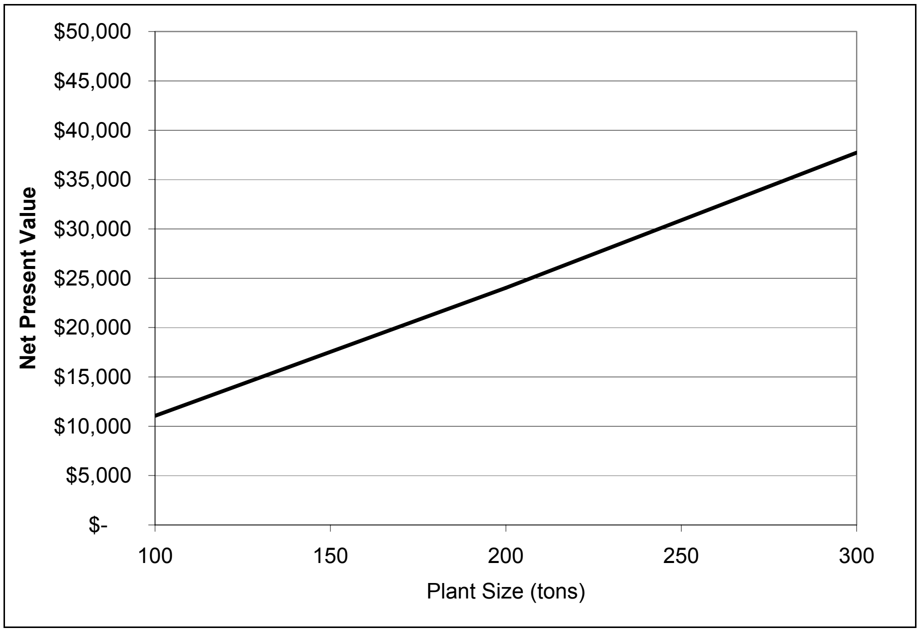

Figure 8 – Net Present Value for Chiller Isolation

Boiler Isolation Results

Results from Climate Zones 3 and 12 showed that pump power costs go down, but pump energy in hot water systems provides beneficial heating, so any reduction in pump power results in a correspondingly higher boiler operation. The savings of this measure are due almost entirely to the reduced part load boiler operation.

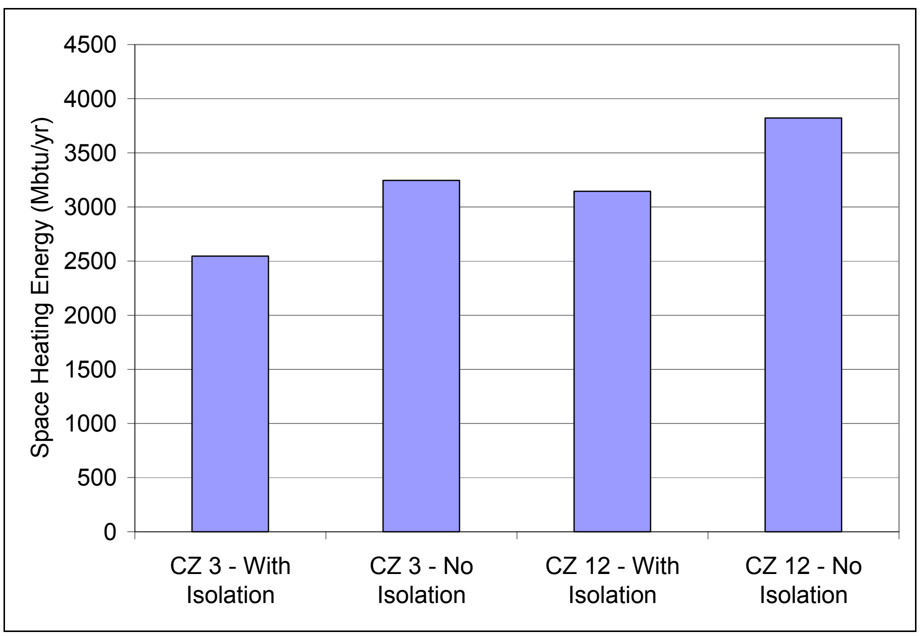

Figure 9 – Boiler Isolation Heating Energy Savings

Table 5 shows the pump and boiler energy savings per installed kBtuh of heating capacity in each climate zone. It also shows the energy cost savings based on present worth factors of $1.37/kWh and $7.03/therm.

Table 5 – Savings from Boiler Isolation

Climate Zone	Pump Energy Savings (kwh/kBtuh)	Boiler Energy Savings (therms/kBtuh)	$/kBtuh
3	0.07	1.32	$ 9.39
12	0.08	1.28	$ 9.09

We conservatively estimated a statewide average savings of $9.00/kBtuh. We used this same number for all plant sizes. Table 6 shows the life-cycle cost for boiler isolation valves for several plant sizes. Clearly, boiler isolation is highly cost effective except for very small hot water plants, which are very unlikely to have multiple boilers. This is also illustrated in Figure 10.

Table 6 – Net Present Value Results for Boiler Isolation

HW Plant Size (kBtuh)	approx ft2	GPM/boiler	pipe size	Cost	Savings	NPV
150	6,000	5.0	3/4"	$1,735	$ 1,350	($385)
250	10,000	8.3	1"	$1,881	$ 2,250	$369
500	20,000	16.7	1-1/4"	$1,961	$ 4,500	$2,540
1,000	40,000	33.3	1-1/2"	$1,961	$ 9,000	$7,040
1,500	60,000	50.0	2"	$2,401	$ 13,500	$11,099
2,000	80,000	66.7	2-1/2"	$2,243	$ 18,000	$15,757
3,000	120,000	100.0	3"	$2,650	$ 27,000	$24,350

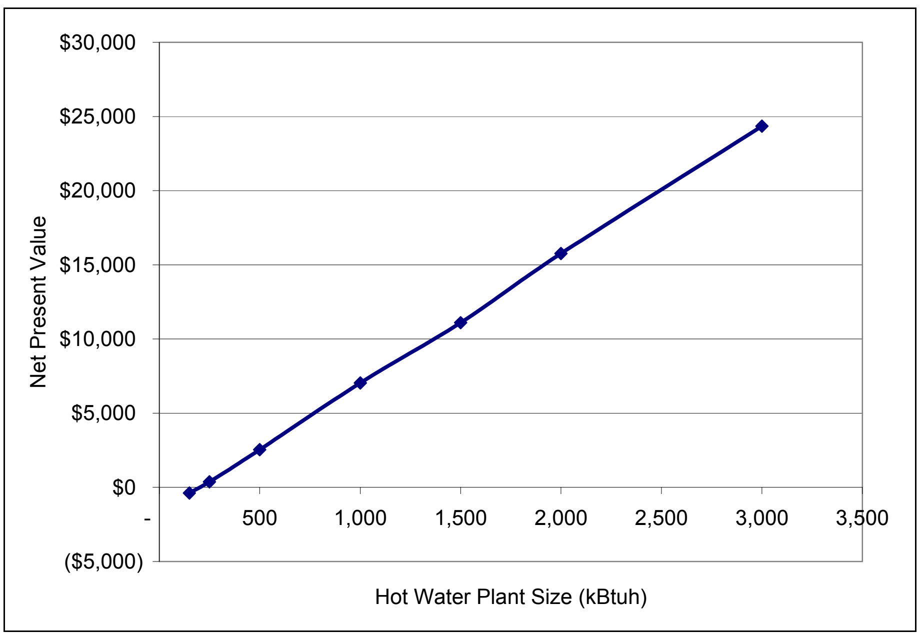

Figure 10 – Net Present Value for Boiler Isolation

Proposed Title 24 2005 Prescriptive Requirement

144(X) Chiller Isolation. When a chilled water plant includes more than one chiller, provisions shall be made so that flow through any chiller is automatically shut off when that chiller is shut off while still maintaining flow through operating chiller(s). The plant shall be designed to operate stably with only one chiller on. Chillers referred to in this section that are piped in series for the purpose of increased temperature differential, shall be considered as one chiller.

144(X) Boiler Isolation. When a hot water plant includes more than one boiler, provisions shall be made so that flow through any boiler is automatically shut off when that boiler is shut off while still maintaining flow through operating boiler(s). The plant shall be designed to operate stably with only one boiler on.

Hydronic Measure #3 – Chilled and Hot Water Temperature Reset

This measure proposes a requirement for chilled and hot water temperature reset controls on constant flow systems (i.e. three-way valves at the heating or cooling coils). Like Standard 90.1, we do not propose a requirement for variable flow systems since the central plant equipment savings from temperature reset is substantially or fully offset by the increased pumping energy in variable flow plants.

Savings

Energy savings from chilled water reset come primarily from the fact that the chiller is more efficient at higher supply temperatures. Energy savings from hot water reset come primarily from reduced pipe losses. Because non-condensing boilers cannot operate with low entering water temperatures without causing flue gas condensation, the hot water supply temperature can be lowered some, which is enough to lower pipe losses, but not enough to significantly reduce flue gas losses.

Existing ASHRAE/IES Standard 90.1-2001 Requirement

The current ASHRAE/IES Standard 90.1-2001 requirement is as follow:

> *6.3.4 Hydronic System Design and Control. HVAC hydronic systems having a total pump system power exceeding 10 hp shall meet provisions of 6.3.4.1 through 6.3.4.4.*
>
> *6.3.4.3 Chilled and Hot Water Temperature Reset Controls. Chilled and hot water systems with a design capacity exceeding 300,000 Btu/h supplying chilled or heated water (or both) to comfort conditioning systems shall include controls that automatically reset supply water temperatures by representative building loads (including return water temperature) or by outside air temperature.*
>
> *Exceptions to 6.3.4.3:*
>
> *(a) Where the supply temperature reset controls cannot be implemented without causing improper operation of heating, cooling, humidifying, or dehumidifying systems.*
>
> *b) Hydronic systems, such as those required by 6.3.4.1, that use variable flow to reduce pumping energy.*

Modeling

We modeled this using the eQUEST (DOE 2.2) program to simulate both heating and cooling systems with and without supply temperature reset.

Base Case Model

We used the same model as the Pump Isolation – Proposal Model (see above) except:

- Three-way control valves on cooling and heating coils for constant flow.
- The thermal conductivity of the hot water loop: UA = 300. This is an estimate based on an R-value of five and 2,000 feet of 3 in. HW piping in unconditioned spaces.
- We did not simulate the pipe loss from the chilled water model because pipe losses are much less than for hot water systems and because the chiller efficiency improvements alone more than justify the measure.
- Chilled water supply temperature = 44 ºF (fixed).
- Hot water supply temperature = 180 ºF (fixed).

Proposal Model

Same as base case except:

- Chilled water supply temperature reset from 44 upwards based on load. The loop supply temperature is reset so that the valve of the worst-case coil is fully open.
- Hot water supply temperature setpoint shall be reset from 180 ºF at 35 ºF outdoor air temperature to 140 ºF at 60 ºF outdoor air temperature with reset temperatures between these points determined through linear interpolation. (The temperature cannot go lower than 140 ºF without causing flue gas condensation due to excessively low entering water temperatures.)

Cost Data

Additional incremental costs resulting from this requirement include costs associated with an additional control point from the control system to the chiller(s)/boiler(s) and the accompanying wiring and programming. We estimate this cost at $1,000 per chilled water or hot water system. This cost is fixed for all plant sizes.

Life-Cycle Cost Analysis

The base and proposed case models were run in Climate Zones 3 and 12. The rationale for the selection of these climate zones is explained above. Savings were converted to dollars per installed ton of capacity for chilled water reset and dollars per installed kBtuh of capacity for hot water reset. Savings were then compared to the fixed cost data to determine the minimum building size at which reset becomes cost effective.

Economic criteria:

- $1.37 as the present value of a kilowatt-hour saved over a 15-year life.
- $7.30 as the present value of a therm saved over a 15-year life.

Table 7 shows the savings per ft^2 from chilled water and hot water temperature reset. At a cost of $1,000 to program the reset controls, chilled water reset is cost effective for chilled water plants over eight tons (100 kBtuh). Hot water reset is cost effective over about 500 kBtuh. Most chilled water plants are larger than 500 kBtuh (40 tons), so for the sake of simplicity, we propose to set the threshold at 500 kBtuh for both chilled and hot water systems.

Table 7 – Temperature Reset Savings and Cost Breakpoints

	Chilled Water Reset	
	Zone 3	Zone 12
Savings ($/ton)	$ 122.14	$ 133.59
Reset Cost	$1,000	$1,000
min. plant size (tons)	8	7
min. plant size (kBtuh)	98	90
	Hot Water Reset	
	Zone 3	Zone 12
Savings ($/kBtuh)	$ 2.18	2.00
Reset Cost	$1,000	$1,000
min. plant size (kBtuh)	459	501
approximate area (ft2)	17,340	18,895

Proposed Title 24 2005 Prescriptive Requirement

144(z) Chilled and Hot Water Temperature Reset Controls. Chilled and hot water systems with a design capacity exceeding 500,000 Btu/h supplying chilled or heated water (or both) shall include controls that automatically reset supply water temperatures by representative building loads or by outside air temperature.

Exception to 144(z): Hydronic systems that use variable flow to reduce pumping energy in accordance with 144(x) [variable flow requirement section above].

The exception for humidity control was deleted because it is not applicable in California's mild climate. Also, even in humid climates, if valve demand is used to control reset, the impact on humidity is minor.

Hydronic Measure #4 – Isolation Valves and VSDs on Water-Loop Heat Pump Systems

This measure proposes a requirement for isolation valves on water-loop (hydronic) heat pumps and variable speed drives for the pumps serve water-loop heat pumps.

Savings

Isolation valves shut off flow to a heat pump whenever the compressor is not running. This reduces flow and causes the pump to "ride up its curve," reducing pump power. Pump energy savings are even higher when variable speed drives are used along with isolation valves.

Existing ASHRAE/IES Standard 90.1-2001 Requirement

The current ASHRAE/IES Standard 90.1-2001 requirement is as follow:

> *6.3.4 Hydronic System Design and Control. HVAC hydronic systems having a total pump system power exceeding 10 hp shall meet provisions of 6.3.4.1 through 6.3.4.4.*
>
> *…*
>
> *6.3.4.4 Hydronic (Water Loop) Heat Pump Systems. Each hydronic heat pump shall have a two-position automatic valve interlocked to shut off water flow when the compressor is off.*

Modeling

We used the eQUEST (DOE 2.2) program to model a building with water-loop heat pumps with and without isolation valves. For the model with isolation valves, we modeled the loop pumps both with and without variable speed drives. We took the aggregate pump energy savings per ton and compared it to the costs of valves and the associated controls.

Base Case Model

- Standard one-story office building.
- WLHP (water-loop heat pump) system. Five zones (one per exposure + interior). All heat pumps will be sized at 150% of peak load.
- No airside economizer, just minimum ventilation.
- Heat pumps do not have an isolation valve; full flow occurs whenever the loop pump is active.
- Cooling tower with variable speed drive maintaining condenser water supply temperature <= 90 ºF.
- Boiler controlled to maintain condenser water supply temperature >=60 ºF.
- Fixed speed pump.
- WLHP coil delta T = 10 ºF.

- WLHP coil pressure drop = 20 ft.
- Piping loop pressure drop = 60 ft.
- Fluid cooler pressure drop = 10 ft.

Proposal Model

Same as base case except:

- Each water-loop heat pump unit has an isolation valve that shuts off loop flow through the unit when the unit's compressor is off.
- Variable speed drive (VSD) on condenser water pump.
- VSD is controlled to maintain fixed differential pressure of 20 ft. at the most remote coil.

Cost Data

The additional components required for this proposal that result in increased incremental cost include the following:

- Isolation valves at each heat pump.
- A variable speed drive per loop pump.

Table 8 shows the cost for electric isolation valves by pipe size. This includes installation costs and a multiplier to convert from national averages to California average using Means 2002 Mechanical Cost Data.

In addition to the isolation valve itself is the cost to control the valve. The valve is interlocked to the compressor. This requires about ½ to one hour of labor and no additional materials. We estimate a fixed cost of $75 per valve for controls.

Table 8 – Electric Isolation Valve Costs

code	size	total cost	CA mult.	total
13838 - 7210	1/2"	$ 218	113	$ 246
7220	3/4"	$ 325	113	$ 367
7230	1"	$ 390	113	$ 441
7240	1.5"	$ 425	113	$ 480

Figure 12 (see below) shows variable speed drive costs (also from Means). In addition to the drive we have added a fixed cost of $3,500 for a differential pressure sensor and controls for the loop pump. These control costs do not vary with pump size.

Life-Cycle Cost Analysis

We ran the models in Climate Zones 3 and 12 and divided the savings by the design loop water flow (in gpm) to get savings/gpm. The savings per gpm was similar for both climate zones so we used the worst case (Zone 3) to be conservative. Figure 11 shows the pump energy in Climate Zone 3 for the base case and for the proposal with variable flow system (isolation valves at the heat pumps) both riding the pump curve and with a VSD on the pump.

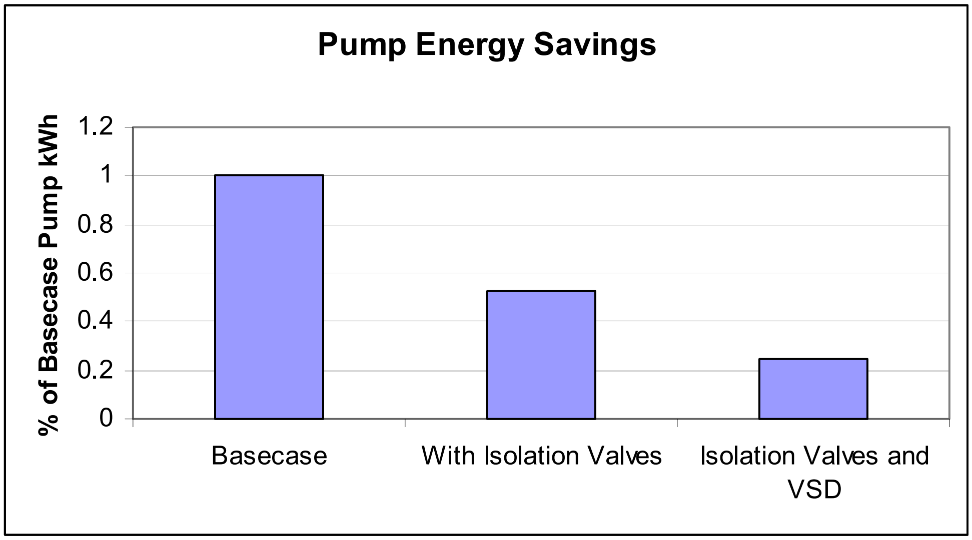

Figure 11 – Pump Energy Savings for the Variable Flow WLHP Measure

Table 9 lists isolation valve costs for heat pump sizes from ¾ to 5 tons. This was based on a condenser water temperature rise of 10 ºF delta T and the pipe size using our office standards for pipe sizing.

Table 9 – Isolation Valve Costs per Heat Pump as a Function of Heat Pump Size

Tons	GPM	pipe size	Valve Cost	Valve+Controls
0.75	1.8	1/2"	$ 246	$ 321
1	2.4	1/2"	$ 246	$ 321
1.5	3.6	3/4"	$ 367	$ 442
2	4.8	3/4"	$ 367	$ 442
3	7.2	1"	$ 441	$ 516
4	9.6	1"	$ 441	$ 516
5	12	1"	$ 441	$ 516

Table 10 shows costs and savings for loop pumps ranging from 3 to 30 hp. We estimated the pump brake horsepower (bhp) using an assumed percent load on the motor of 80%. This is because standard motors are only available in discrete sizes such as 5 and 7.5 hp and are rarely sized exactly for the load. Our field experience is that 80% is a reasonable average of the pump motors specified. We calculated the total loop flow (gpm) based on design delta T, head, pump brake horsepower, and pump efficiency. The total savings are based on the $/gpm savings from the simulation model. The savings include savings from both the isolation valves and the variable speed drive.

We assumed a distribution of heat pump sizes based on our design and field experience. We assumed 50% of the total cooling capacity was supplied by 1-ton units, 30% of the capacity was supplied by 3-ton units and the remainder of the capacity by 5-ton units. Based on this distribution, we calculated the numbers of heat pumps and the corresponding total cost for isolation valves. The total cost includes the VSD, the isolation valves, and all related controls.

Table 10 shows that variable speed drives and isolation valves can be justified on all WLHP systems with a total design pump horsepower >= 5 hp.

Table 10 – Variable Speed Costs and Savings

Motor HP	VSD Cost	VSD+Ctrls	bhp	GPM	Savings	1 tons	3 tons	5 tons	Valve Costs	Total Cost	NPV
3	$ 2,486	$ 5,986	2.4	81	$ 12,789	17	3	1	$ 7,890	$ 13,876	$ (1,086)
5	$ 2,769	$ 6,269	4	136	$ 21,316	28	6	2	$ 13,149	$ 19,418	$ 1,898
7.5	$ 3,786	$ 7,286	6	203	$ 31,973	42	8	3	$ 19,724	$ 27,009	$ 4,964
10	$ 3,786	$ 7,286	8	271	$ 42,631	56	11	5	$ 26,299	$ 33,584	$ 9,047
15	$ 4,407	$ 7,907	12	407	$ 63,947	85	17	7	$ 39,448	$ 47,355	$ 16,592
20	$ 5,961	$ 9,461	16	542	$ 85,262	113	23	9	$ 52,597	$ 62,058	$ 23,204
25	$ 6,865	$ 10,365	20	678	$ 106,578	141	28	11	$ 65,746	$ 76,111	$ 30,466
30	$ 7,684	$ 11,184	24	813	$ 127,893	169	34	14	$ 78,896	$ 90,080	$ 37,813

Proposed Title 24 2005 Prescriptive Requirement

144(x) Water Loop Heat Pump Systems. Water-Loop Heat Pump Systems having a total pump system power exceeding 5 hp shall have controls and/or devices (such as variable speed control) on each coil loop pump that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow. The controls or devices shall be controlled as a function of desired flow or to maintain a minimum required differential pressure. Differential pressure shall be measured at or near the most remote heat pump or the heat pump requiring the greatest differential pressure. Each heat pump shall have a two-position automatic valve interlocked to shut off water flow when the compressor is off.

Alternate language can reference the VSD requirement proposed in the next section as follows:

144(x) Water Loop Heat Pump Systems. Water-Loop Heat Pump Systems having a total pump system power exceeding 5 hp shall have flow controls that meet the requirements of 144(Y). Each heat pump shall have a two-position automatic valve interlocked to shut off water flow when the compressor is off.

Hydronic Measure #5 – Variable Speed Drives (VSDs)

This measure proposes a requirement for variable speed drives and controls for variable-flow chilled and auxiliary condenser water pump systems. As the system flow decreases, a normal motor will ride the pump curve, which decreases the power requirement. However, by using a variable speed drive, the same decrease in system flow will result in a much greater drop in power requirement.

Hot water systems are not targeted by this proposal. Because the energy saved from dropping the pump curve to the variable speed drive curve is offset by increasing the heating required from the boilers, it is our experience that variable speed drives do not pay back on variable flow hot water systems.

Existing ASHRAE/IES Standard 90.1-2001 Requirement

> *Individual pumps serving variable flow systems having a pump head exceeding 100 ft and motor exceeding 50 hp shall have controls and/or devices (such as variable speed control) that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow. The controls or devices shall be controlled as a function of desired flow or to maintain a minimum required differential pressure. Differential pressure shall be measured at or near the most remote heat exchanger or the heat exchanger requiring the greatest differential pressure.*

Note that VSDs are already bundled with the WLHP requirement from the previous measure. We will only consider chilled water and auxiliary condenser water systems here.

Modeling

We used eQUEST (DOE 2.2) to model an office building with a variable flow chilled water system with and without a variable speed drive. We varied the pump system head as well to represent a range system configurations.

Base Case Model

- Standard 200,000 ft^2 office building.
- VAV Reheat.
- One air handler with two-way chilled water valve.
- Water cooled chilled water plant.
- Primary/secondary variable chilled water flow scheme.
- Plant will be sized at 125% of peak load.
- Two equally sized centrifugal chillers, with isolation valves.
- Constant speed secondary chilled water pump, i.e. pump rides up the pump curve as load and chilled water flow decrease.
- Secondary pump head = 80 ft (20 ft for coil, 60 ft for secondary loop).

Proposal Model

Same as base case except:

- Variable speed drive on secondary chilled water pump.
- We ran two types of VSD control:
    - *Sensor at Coil – Fixed Differential Pressure Setpoint.* The speed of the VSD is modulated in order to maintain a constant differential pressure set-point. As load goes down, cooling coil control valves close and the differential pressure between the chilled water supply and return pipes increases so the drive slows the pump down to maintain constant pressure. The sensor is located at the far end of the loop, near the takeoffs to the coils. The setpoint is the maximum design head of the coil plus 1/2 of the throttling range.
    - *DDC – Valve Reset.* The differential head pressure is reset so that the system pressure is sufficient to provide the required flow to the “worst-case” coil, that requiring the most pressure. With this option, DOE-2 determines the position of the control valves of all the coils attached to the loop, and adjusts the loop’s pressure so that the valve on the worst-case coil is fully open, which minimizes the pump energy that is wasted by throttling valves. In practice, this control sequence usually requires a direct-digital control system.

Cost Data

Additional components which cause an incremental increase in cost are:

- Variable speed drive (depends on pump horsepower – see Figure 12).
- Differential pressure sensor and controls. This is a fixed cost regardless of plant size. We estimate this cost at $4,000. This covers the differential pressure sensor and its controls as well as the controls for a variable speed drive.

Figure 12 shows installed cost data for variable speed drives. This data is from MEANS Mechanical Cost Data 2002 and includes the 113% California multiplier described above. The MEANS description is “Variable Frequency Drives/Adjustable Frequency Drives, Enclosed (NEMA 1), 460 volt”.

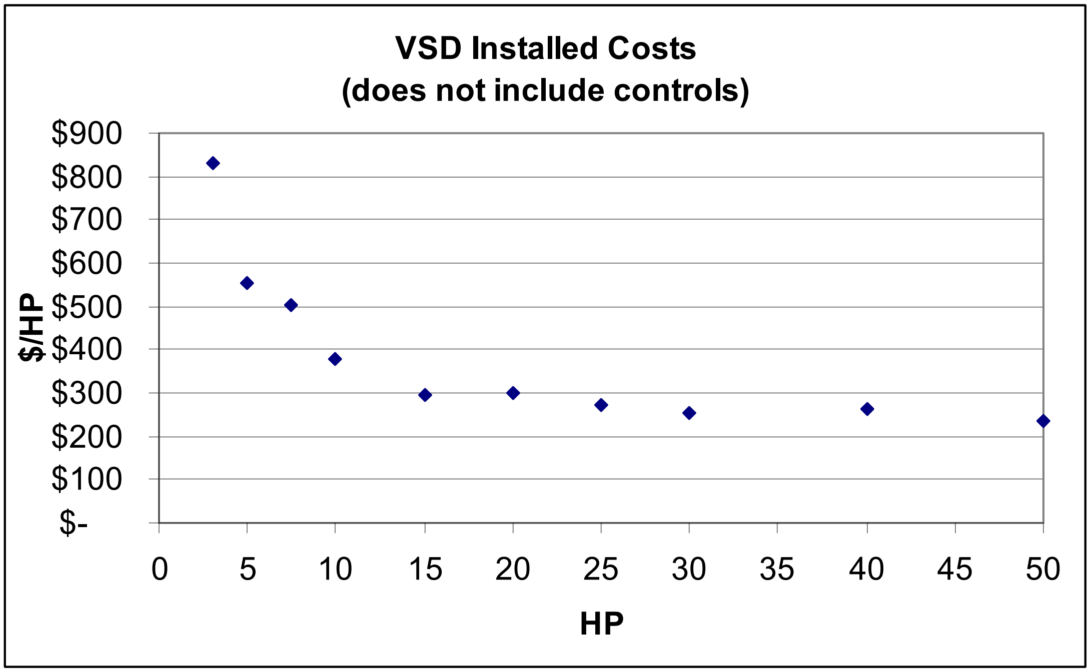

Figure 12 – Variable Speed Drive Costs

Life-Cycle Cost Analysis

The models were run in Climate Zones 3 and 12; the reasons for this are described above. Energy savings results were converted to $/installed hp and compared to the cost estimate to determine the minimum hp at which the proposal becomes cost effective.

Figure 13 shows how pump energy varies with the different methods of head setpoint control.

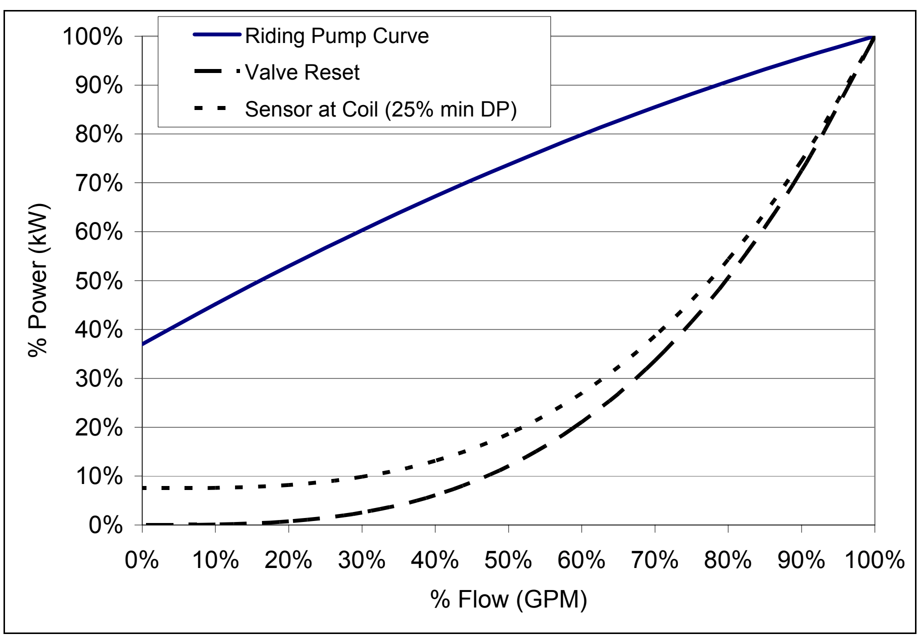

Figure 13 – Variable Speed Pumping in DOE-2

Figure 14 shows that variable speed drives are more cost effective with valve reset than with fixed differential pressure setpoint, and that they are more cost effective in hot climates (Climate Zone 12) than in mild ones (Climate Zone 3), but in all circumstances, they are cost effective above 5 hp.

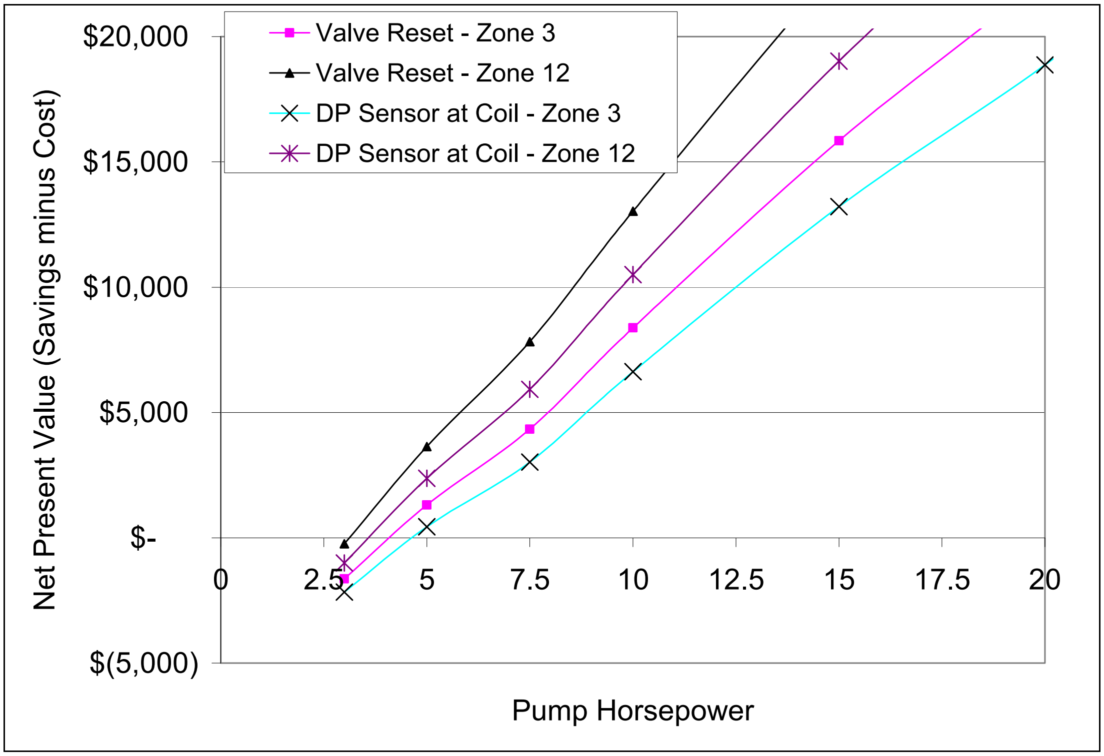

Figure 14 – Chilled Water VSD Life-Cycle Costs

Proposed Title 24 2005 Prescriptive Requirement

Individual pumps serving variable flow systems and having a motor horsepower exceeding 5 hp shall have controls and/or devices (such as variable speed control) that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow. The controls or devices shall be controlled as a function of desired flow or to maintain a minimum required differential pressure. Differential pressure shall be measured at or near the most remote heat exchanger or the heat exchanger requiring the greatest differential pressure.